Designing with Geosynthetics

Second Edition

Robert M. Koerner, Ph. D., P. E.

Bowman Professor of Civil Engineering
Director, Geosynthetic Research Institute
Drexel University

PRENTICE HALL, Englewood Cliffs, N.J. 07632

Library of Congress Cataloging-in-Publication Data

Koerner, Robert M.
Designing with geosynthetics.

Includes bibliographies and index.
1. Geosynthetics. I. Title.
TA455.G44K64 1990 620.1'9 88-33591
ISBN 0-13-202300-8

Editorial/production supervision and
interior design: Joe Scordato
Cover design: Diane Saxe
Manufacturing buyer: Mary Noonan

Printed in the United States of America

10 9 8 7 6 5 4 3 2

ISBN 0-13-202300-8

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Simon & Schuster Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

TABLE 2.13 RECOMMENDED PARTIAL FACTORS OF SAFETY VALUES FOR USE IN EQUATION 2.19

	Various partial factors of safety				
Application	Soil clogging and binding	Creep reduction of voids	Intrusion into voids	Chemical clogging	Biological clogging
retaining wall filters	2.0 to 4.0	1.5 to 2.0	1.0 to 1.2	1.0 to 1.2	1.0 to 1.3
underdrain filters	2.0 to 4.0	1.0 to 1.5	1.0 to 1.2	1.2 to 1.5	1.2 to 1.5
erosion control filters	2.0 to 4.0	1.0 to 1.5	1.0 to 1.2	1.0 to 1.2	1.2 to 1.5
landfill filters	2.0 to 4.0	1.5 to 2.0	1.0 to 1.2	1.2 to 1.5	1.5 to 3.0
gravity drainage	2.0 to 4.0	2.0 to 3.0	1.0 to 1.2	1.2 to 1.5	1.2 to 1.5
pressure drainage	2.0 to 3.0	2.0 to 3.0	1.0 to 1.2	1.1 to 1.3	1.1 to 1.3

where

q_{allow} = the allowable flow rate,
q_{ult} = the ultimate flow rate,
FS_{SCB} = the factor of safety for soil clogging and blinding,
FS_{CR} = the factor of safety for creep reduction of void space,
FS_{IN} = the factor of safety for adjacent materials intruding into geosynthetic's void space,
FS_{CC} = the factor of safety for chemical clogging, and
FS_{BC} = the factor of safety for biological clogging.

2.4 GEOTEXTILE FUNCTIONS AND MECHANISMS

The initial section on geotextiles alluded to the various applications (there are indeed many of them) falling into categories vis-a-vis their major function. These categories, separation, reinforcement, filtration, drainage, and moisture barrier (when impregnated), when properly identified, lead to the concept of *designing by function*, which is the thrust of this book. The purpose of this section is to demonstrate what these functions mean to geotextiles and to elaborate on the actual mechanisms involved within each type of function.

2.4.1 Separation

The concept of separation can perhaps be illustrated by the engineering adage that "10 pounds of stone placed on 10 pounds of mud results in 20 pounds of mud." Thus the definition of a geotextile serving in a separation function is as follows:

Geotextile separation: the introduction of a flexible synthetic barrier placed between dissimilar materials so that the integrity and functioning of both materials can remain intact or be improved.

When placing stone on fine or mixed soil there are two simultaneous mechanisms that tend to occur over time: one is that the soil fines attempt to enter into the voids of the stone, thereby ruining drainage capability; the other is that the stone attempts to intrude into the soil, thereby ruining the stone's strength. When this occurs we have a situation that has been called "sacrificial stone," which is all too often the case without the use of a proper separating geotextile. The two mechanisms are shown schematically in Figure 2.21.

2.4.2 Reinforcement

Geotextiles, being a type of tensile-strength material, can nicely complement those materials weak in tension. Thus low-strength soils are prime targets for geotextile reinforcement. A convenient definition is the following:

Geotextile reinforcement: the often synergistic improvement of system strength created by the introduction of a geotextile (good in tension) into a soil (poor in tension but good in compression) or other disjointed and separated material.

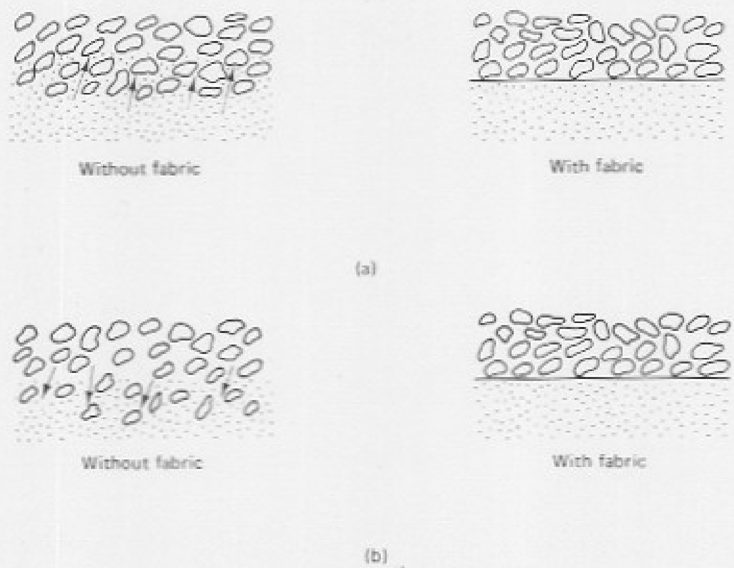

Figure 2.21 Different mechanisms involved in the use of geotextiles involved in the separation function. (a) Mechanism of soil fines pumping into stone voids and prevention of mechanism using geotextiles. (b) Mechanism of stone intrusion into soil subgrade and prevention of mechanism using geotextiles.

Improvement in strength can be evaluated in a number of ways. The triaxial tests conducted by Broms [38] illustrate the beneficial effects of the geotextile when properly placed. Figure 2.22 shows two sets of triaxial tests on dense sand samples at confining pressures of approximately 3 lb./in.^{2} (20 kPa) and 30 lb./in.^{2} (210 kPa) for different soil and geotextile configurations. Curves 1 represent the base-line data of the sand by itself. Curves 2 have geotextiles on the top and bottom of the soil and do not show improved strength behavior. Since these are nonacting dead zones in conventional triaxial tests, that is logical behavior. It is instructive in itself, however, for it is teaching that if the geotextile is placed at the wrong location, it will have no beneficial effect. Upon placing the geotextile in the center of the sample, or at the one-third points, however, beneficial effects are easily seen. Here the fabric interrupts potential shear zones and has the influence of increasing the overall strength of the now-reinforced soil. As expected, the double layers placed at the one-third points (Curves 4) are more beneficial than the one layer placed at the center of the sample (Curves 3).

Within the general function of geotextile reinforcement of soils are three different mechanisms: (1) membrane type, (2) shear type, and (3) anchorage type.

2.4.2.1 Membrane Type

Membrane reinforcement occurs when a vertical load is applied to a geotextile on a deformable soil. Depending on the depth that the geotextile is placed from the load, it is well established [39] that

$$\sigma_h = \frac{P}{2\pi z^2}\left[3 \sin^2 \theta \cos^3 \theta - \frac{(1 - 2\mu) \cos^2 \theta}{1 + \cos \theta}\right] \tag{2.20}$$

where

σ_h = the horizontal stress at depth z and angle θ,
P = the applied vertical load,
z = the depth beneath surface where σ_h is being calculated,
μ = Poisson's ratio, and
θ = the angle from vertical beneath surface load P.

Note that directly beneath the load, where $\theta = 0$ deg.,

$$\sigma_h = -\frac{P}{\pi z^2}\left(\frac{1}{2} - \mu\right) \tag{2.21}$$

Since μ is less than 0.5, σ_h is negative (which is tension), that is, the applied vertical downward load produces tension on a horizontal plane beneath it. Thus tension results in the geotextile, which is precisely the objective of placing it there. As seen in the equation, the larger the magnitude of P, the higher the fabric's stress. Also, the closer the fabric is to the load (low value of z), the higher the fabric's stress. Many situations in which geotextiles are placed on soft soils or in a yielding situation use this particular reinforcement mechanism.

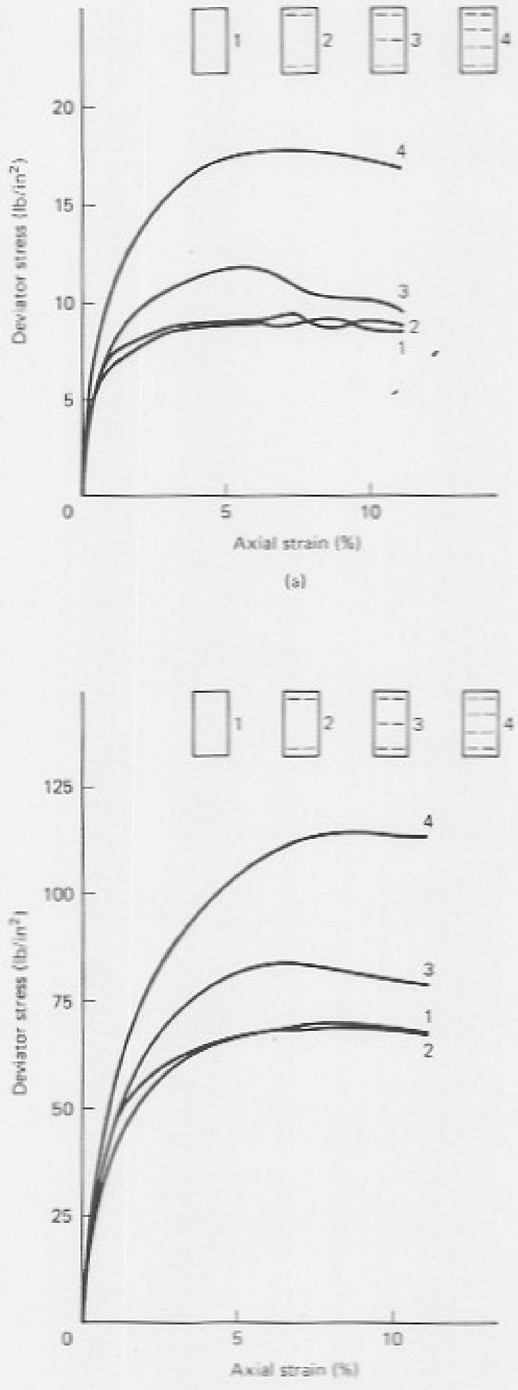

Figure 2.22 Triaxial test results showing influence of geotextiles placed at various locations within soil specimen (after Broms [38]). (a) Dense sand at 3 lb./in.^{2} (21 kPa) confining pressure. (b) Dense sand at 30 lb./in.^{2} (210 kPa) confining pressure.

2.4.2.2 Shear Type

Shear reinforcement was illustrated in Figure 2.22 but can be better visualized by means of direct shear tests. Here a geotextile placed on a soil is loaded in a normal direction, and then the two materials are sheared at their interface. The resulting shear strength parameters (cohesion and friction angle) can be obtained as described in Section 2.2.3.10. Recall that the values can be compared to the shear strength parameters of the soil by itself and a comparison of numerical values results. These ratios (sometimes called efficiencies) have limiting values of zero to unity. A value higher than 1 would have the failure plane moving into the soil itself.

2.4.2.3 Anchorage Type

Anchorage reinforcement is similar to the shear type just described, but now the soil acts on both sides of the geotextile as a tensile force tends to pull it out of the soil. The laboratory modeling of this type of mechanism is similar to direct shear except that now soil is in both halves of the shear box and the fabric extends out of the shear box at its center. Here it is gripped externally and pulled, while normal stresses act on the soils and fabric within the shear box. Section 2.2.3.11 describes this situation and also gives typical values in terms of shear strength parameters by themselves and efficiencies as just discussed. Another approach could be to express the efficiency as a function of the amount of mobilized fabric strength. Wide-width tensile values should be used in this case. Here efficiencies greater than unity (via a bearing capacity mechanism) can easily occur. As with the other types of mechanisms of geotextile reinforcement, this category of fabric anchorage is used quite often. The applications mentioned in Chapter 1 illustrate the point.

Calculation-wise we will use the shear strength mobilized by the geotextile with the soil above and with the soil below and arithmetically sum the two values as the limiting anchorage value. In the absence of anchorage tests, we will use direct shear generated values for this purpose.

2.4.3 Filtration

The geotextile function of filtration involves the movement of liquid through the fabric itself (i.e., across its manufactured plane). At the same time, the fabric serves the purpose of retaining the soil on its upstream side. Both adequate permeability (requiring an open fabric structure) and soil retention (requiring a tight fabric structure) are required simultaneously. A third factor is also involved, that being the long-term soil-to-fabric flow compatibility that will not clog during the lifetime of the system. Thus a definition of filtration is:

> *Filtration:* the equilibrium fabric-to-soil system that allows for free liquid flow (but no soil loss) across the plane of the fabric over an indefinitely long period of time.

This function of filtration is a major one (recall the application areas presented in Section 1.3.3) for the geotextile industry. Geotextiles, when properly designed and constructed, offer a practical remedy to many problems involving the flow of liquids.

2.4.3.1 Permeability

This particular discussion of fabric permeability refers to cross-plane permeability when liquid flow is perpendicular to the plane of the fabric. Some of the fabrics used for this purpose are relatively thick and compressible. For this reason the thickness is included in the permeability coefficient and is used as a "permittivity," which was previously defined as

$$\Psi = \frac{k_n}{t} \tag{2.9}$$

where

Ψ = the permittivity,
k_n = the cross-plane permeability coefficient, and
t = the thickness at a specified normal pressure.

The testing for geotextile permittivity was covered in Section 2.2.4.4.

2.4.3.2 Soil Retention

As one allows for greater flow of water through the geotextile, the void spaces in it must be made larger. There is, however, a limit—that being when the upstream soil particles start to pass through the fabric voids along with the flowing liquid. This leads to an unacceptable situation called "soil piping," in which the finer soil particles are carried through the fabric, leaving larger soil voids behind. The liquid velocity then increases, accelerating the process, until the soil structure begins to collapse. This collapse often leads to minute sinkhole-type patterns that grow larger with time.

This entire process is prevented by making the geotextile voids small enough to retain the soil on the upstream side of the fabric. It is the coarser soil fraction that must be initially retained; this is the targeted soil size in the design process. These eventually block the finer sized particles. Fortunately, filtration concepts are well established in the design of soil filters, and those same ideas will be used to design an adequate geotextile filter.

There are a number of approaches to accomplishing soil retention, all of which use the soil particle size characteristics and compare them to the O_{95} size (as determined by the AOS test) of the fabric. The simplest of these methods examines the percentage of soil passing the No. 200 sieve (= 0.074 mm). According to Task Force 25, the following is recommended [40]:

1. Soil $\leq$ 50% passing the No. 200 sieve
   AOS of the fabric $\geq$ No. 30 sieve (i.e., $O_{95} < 0.59$ mm)
2. Soil $>$ 50% passing the No. 200 sieve
   AOS of the fabric $\geq$ No. 50 sieve (i.e., $O_{95} < 0.297$ mm)

Slightly more restrictive is the recommendation of Carroll for the 0_{95} size in millimeters, which is the following [41]:

$$0_{95} < (2 \text{ or } 3)\ d_{85} \tag{2.22}$$

where d_{85} is the particle size in millimeters for which 85% of sample is finer. Finally, the most conservative method is after Giroud [42], who presents a table for recommended 0_{95} values (i.e., the opening size in millimeters corresponding to the AOS value) in terms of relative density (D_R), coefficient of uniformity (CU), and average particle size (d_{50}) (see Table 2.14). One of these three approaches should be used. The approach should be chosen on the basis of the criticality of the situation being considered, since the approaches are restrictive to different degrees.

TABLE 2.14 RELATIONSHIPS USED TO OBTAIN FABRIC OPENING SIZE TO PREDICT EXCESSIVE LOSS OF FINES DURING FILTRATION[a]

Relative density	$1 < CU < 3$	$CU > 3$
Loose ($D_R < 50\%$)	$0_{95} < (CU)\ (d_{50})$	$0_{95} < (9d_{50})/CU$
Intermediate ($50\% < D_R > 80\%$)	$0_{95} < 1.5(CU)\ (d_{50})$	$0_{95} < (13.5d_{50})/CU$
Dense ($D_R > 80\%$)	$0_{95} < 2(CU)\ (d_{50})$	$0_{95} < (18d_{50})/CU$

Source: After Giroud [42]

[a] d_{50}, Soil particle size corresponding to 50% finer; CU, coefficient of uniformity ($= d_{60}/d_{10}$); d_{10}, soil particle size corresponding to 10% finer; d_{60}, soil particle size corresponding to 60% finer; 0_{95}, apparent opening size of geotextile (if data are not given by the manufacturer, this value is approximately the AOS sieve value in millimeters).

2.4.3.3 Long-Term Compatibility

Perhaps the most asked question in the use of geotextiles in hydraulic related systems is, "Will it clog?" Obviously, some soil particles will embed themselves within the fabric structure, but the question really asks if the fabric will completely clog, such that the flow of liquid through it will be completely shut off. The question can be directly answered by taking a soil sample and the candidate geotextile(s) and testing them in the laboratory in either gradient ratio tests [27] to seé that the $GR \leq 3.0$, or long-term flow tests [26] to see that the terminal slope of the flow rate versus time curve is essentially zero (recall Sections 2.2.5.5 and 2.2.5.4).

Another approach to a suitable answer to the clogging question posed is simply to avoid situations that have been known to lead to severe clogging problems. From experience it has been shown that three conditions are necessary to have a high likelihood of complete soil clogging of geotextile filters:

1. cohesionless sands and silts,
2. gap-graded particle size distribution, and
3. high hydraulic gradients.

If these conditions are present, one should avoid the use of geotextiles altogether and should instead use a soil filter (although the chances are that it too will clog), or should open up the geotextile to the point where some soil loss will occur. This of course can be done only if the upstream conditions will permit such soil loss. Recommended values for such situations are:

- *Woven fabrics:* POA $\geq$ 6%
- *Nonwoven fabrics:* porosity $\geq$ 40% under the actual stress conditions that the geotextile is serving.

Other situations that have caused clogging problems of geotextiles are filtration situations involving very high alkalinity groundwaters. For high pH liquids, the slowing of flow at the fabric interface can cause a calcium, sodium, or magnesium precipitate to be deposited, thereby blinding the fabric's upstream surface. The potential of biological clogging has often been considered, but for groundwater the likelihood is relatively remote. Conversely, for municipal landfill leachate the likelihood is relatively high.

This discussion of soil-to-fabric compatibility assumes the establishment of a set of mechanisms that are in equilibrium with the flow regime being imposed on the system. Numerous attempts at insight into these phenomena have been attempted, most of which suggest a number of possibilities [43], including upstream soil filter, blocking, arching, and partial clogging. These are shown schematically in Figure 2.23. Obviously, a number of them are working together simultaneously, and just what mechanism dominates under what conditions of soil type, fabric type, and flow regime is still an issue that needs further research.

2.4.4 Drainage

Fabrics placed in such a way as to transmit liquid in the plane of their structure provide a drainage function. Thus a definition of drainage is

> *Drainage:* the equilibrium fabric-to-soil system that allows for free liquid flow (but not soil loss) in the plane of the fabric over an indefinitely long period of time.

All fabrics can provide such a function but to widely varying degrees [22]. For example, a thin woven fabric, by virtue of its fibers crossing over and under one another, transmits liquid within the spaces created at these crossover points, but to a very modest degree. Conversely, the thick, needle-punched nonwoven fabrics have considerable void space in their structure, and this space is available for liquid transmission. Furthermore (as a preview of the materials to be discussed in Chapters 4 and 6), geonets and geocomposites can transmit much more liquid than can geotextiles, even thick, bulky ones. Obviously, proper design will dictate just what type of geosynthetic is necessary.

It will be noted that this discussion on drainage overlaps considerably the preceding section on filtration. Indeed, regarding these two subjects, and except from the consideration of flow direction, the soil retention and long-term compatibility concepts are the same.

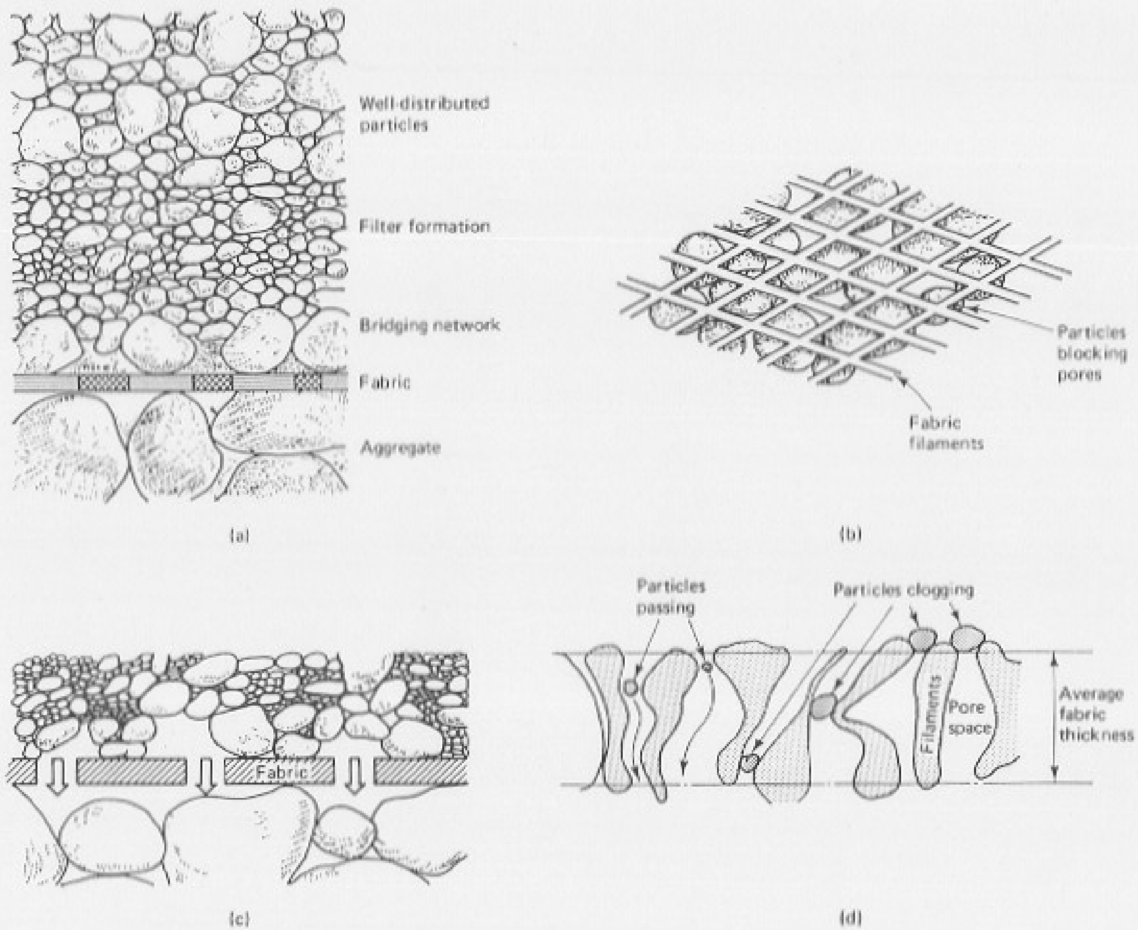

Figure 2.23 Various hypothetical mechanisms involved in long-term soil-to-fabric flow compatibility (after McGown [43]). (a) Formation of an upstream soil filter. (b) Upstream particles blocking geotextile openings. (c) Upstream particles arching over geotextile openings. (d) Soil particles clogged within geotextile structure.

2.4.4.1 Permeability

Referring now to in-plane permeability for the drainage function, we must consider that the fabric's thickness will decrease with increasing normal stress on it. For this reason we have previously defined a term called "transmissivity" as follows:

$$\theta = k_p t \tag{2.13}$$

where

θ = the transmissivity,
k_p = the in-plane permeability coefficient, and
t = the thickness at a specified normal pressure.

The testing method for geotextile transmissivity was covered in Section 2.2.4.6.

2.4.4.2 Soil Retention

The criteria used to design the opening spaces of a geotextile so that it retains the adjacent soil were covered in Section 2.4.3.2. The concepts and design guides are precisely the same for the drainage function.

2.4.4.3 Long-Term Compatibility

As with the filtration function, the compatibility of the soil with the geotextile must be ensured over the lifetime of the system being built. The criteria discussed in Section 2.4.3.3 hold for drainage situations exactly as they do for filtration situations.

2.4.5 Moisture Barrier

With regard to the typical kinds of fabrics being discussed in this chapter, a moisture barrier can be created by rendering the fabric relatively impermeable to both cross-plane and in-plane flow. One is in essence creating a geomembrane, albeit one having a fabric structure rather than being a continuous sheet of polymeric material. The moisture barrier referred to here is generally obtained by spraying bituminous, rubber-bitumen, or polymeric mixes into a properly deployed geotextile thus creating an in-situ moisture barrier. While the permeability referred to is obviously not zero (on an absolute basis, no geosynthetic has zero permeability), it is very low compared to that of the original geotextile. Quite possibly its permeability is now in the range 2×10^{-6} to 2×10^{-8} ft./min. (10^{-6} to 10^{-8} cm/s). This is comparable to the permeability coefficient of many fine-grained soils in the clay family.

Within this function of moisture barrier, we obviously refer to the impedance of the flow of liquid. However, we also refer to the movement of *vapor* across the barrier. Numerous situations in which the system on one side of the barrier must be kept free of liquid *and* its vapor fall into this category.

2.4.6 Combined Functions

The introduction to this chapter described "design by function." The procedure was outlined as identifying the geotextile's primary function and designing accordingly. Where geotextiles are used for a single function, this can indeed be done. However, geotextiles often serve multiple or combined functions. Some examples would be:

1. prevention of crack reflection in asphalt pavement overlays, where both moisture barrier and reinforcement functions are involved;
2. beneath railroad ballast, where separation, reinforcement, filtration, and drainage can all be involved; and
3. in use of fabrics for flexible forming systems to contain grout, where separation, reinforcement, and filtration are involved.

In these situations the primary, secondary, tertiary, etc., functions must all be satisfied. They must all satisfy the required factor of safety. If the situation is properly assessed, the calculated factors of safety will be seen to increase progressively as one proceeds through the primary, secondary, tertiary, etc., functions. If not (i.e., if the factors of safety jump around as one proceeds through the calculations), it only means that the critical functions were not properly assessed to begin with. Thus the minimum factor of safety will always indicate the primary function, the next highest value of factor of safety will indicate the secondary function, and so on. This approach, of course, assumes that a reasonably accurate quantitative analysis can be developed for each of the functions described. This is, in fact, the goal of the next five sections.

2.5 DESIGNING FOR SEPARATION

Specific application areas for geotextiles being used in the separation function were given in Section 1.3.3. There are indeed many specific uses, and one could say in a general sense that geotextiles always serve a separation function. Indeed, if they do not serve this function, the other, usually primary function will not be served properly. This should not give the impression that geotextiles as separators always play a secondary role. Many situations call for separation only, and in such cases the fabrics do indeed serve a noble function.

2.5.1 Overview of Applications

Perhaps the target application that can best illustrate the use of geotextiles as separators is its placement between reasonably firm soil and stone base course, aggregate, or ballast—the soil being below the geotextile, the stone above it. We say "reasonably firm" because it is assumed that the subgrade deflection is not sufficiently large to mobilize uniformly high tensile stress in the fabric. (The application of geotextiles in unpaved roads on soft soils wherein membrane-type reinforcement is developed is treated later in Section 2.6.)

(c) For strength and elongation, the stress-versus-strain curve of the candidate fabric(s) must be known to match up with the grouting pressure and required elongation. This is very much a site-specific situation. Note that woven nylon fabrics with grab strength of 200 lb. (0.90 kN) and elongation at failure of 30% are often used for fabric forms of this type.

2.10.4.9 Summary

To be sure, the use of fabrics as flexible forming systems is an exciting concept simply waiting for new and innovative applications. Contrasted to other geotextile uses, the fabric is sacrificial in most cases (e.g., when grout or concrete is placed within the fabric form). Thus UV degradation is no problem in these cases. For sand-filled bags and tubes, however, it is a definite problem that must be considered.

The design of the fabric follows nicely along lines of other geotextile systems. Strength and elongation considerations are invariably necessary along with proper filtration. Thus the topic is being considered in this section under the category "geotextile design for multiple functions." A good deal of future activity will undoubtedly be seen in this particular application of geotextiles.

2.11 CONSTRUCTION METHODS AND TECHNIQUES USING GEOTEXTILES

2.11.1 Introduction

Although this book is devoted primarily to design topics, it is nevertheless important to consider the constructability of the final design. All too often adequate designs have been negated by the inability to construct them or by improper construction methods. Of course, either situation is disastrous as far as the final system is concerned.

Construction with geotextiles is not particularly difficult as long as it is remembered that the textile product being dealt with weighs typically from 4 to 18 oz./yd.^{2} (140 to 610 g/m^2)—that is, it is not a steel-wire blasting mat! Most building contractors, heavy-construction contractors, land developers, and federal, state, and local construction forces that deal with other types of designed and specified construction materials are well-equipped for handling geotextiles. In fact, it is most interesting to note the adaptability of these groups in devising new and clever geotextile deployment and installation procedures. Freely available literature by manufacturers is also extremely helpful in this regard. There are, however, certain areas where new and unusual techniques are required, and these have had attention drawn to them in their specific sections. They were in the stabilization area (walls and embankments), in the reflective crack prevention area, and in use as flexible forming systems.

One area that does require constant vigilance is that of ultraviolet (UV) light susceptibility. Contractors often fail to recognize that nonstabilized fabrics can be literally destroyed by leaving them exposed to sunlight, especially in southern climates. The work of Raumann [33], originally commented on in Section 2.2.6.6, is reemphasized here to bring attention to this susceptibility. Figure 2.19, if the reader will recall, shows the drastic strength and elongation reduction of both polypropylene and polyester fabrics when exposed to open sunlight. In some cases all strength was lost within 8 weeks! Clearly, there is the utmost need for the contractor to keep the fabric in its protective cover as long as possible and even perhaps to keep it in an enclosure. Once the roll is opened and the fabric is placed in its final position, it must be backfilled *immediately*. Unused portions of rolls must be rerolled and protected. The specification must be clear and the inspection rigid in this regard. When the fabric is UV-stabilized (generally using carbon black in the polymer mixture) this susceptibility is largely reduced, but not entirely eliminated.

2.11.2 Fabric Survivability

Fabric survivability refers to the ability of the fabric to withstand the handling and installation stresses it will receive prior to its being in its final position. It is related to construction equipment, construction technique, subgrade material, subgrade condition, backfill material, backfill size and shape, and so on. Table 2.21 considers these features and rates general geotextile requirements of survivability in categories of low, moderate, high, or very high. Depending on, and keyed into, these categories are a set of survivability requirements that are considered to be minimum geotextile properties for necessary placement in the intended and final position. One such approach to a survivability set of properties is given in Table 2.22, which is a consensus viewpoint from a number of governmental, professional, and manufacturing organizations. The entire document for a number of applications from Task Force #25 is included as Appendix C. It should be emphasized that if the values in this table exceed those calculated on the basis of functional design (as they sometimes will, as pointed out in Section 2.2.6.1 and the data of Table 2.9), the values in the table must be used. Thus calculated design stresses do not always prevail.

2.11.3 Cost and Availability Considerations

Of prime importance to all involved is the cost of the installed geotextile. Although noticeably absent in the book because of changing price indices, site and climate variations, type and quantity of fabric, and so on, a few comments are in order.

The cost of the fabric itself is reasonably related to its mass per unit area. Heavier fabrics cost proportionately more than lighter ones. Note, however, that the installation cost may not be significantly higher for the heavier fabrics. The type of manufacture is also a factor, with woven slit film generally being the least expensive, then nonwoven melt-bonded and needle-punched nonwoven, and then woven monofilament, which is the most expensive on the basis of an equivalent mass per unit area. These comments, however, should in no way sway a design toward preference of one fabric over another. They are offered only to give a feeling for the costs involved. As of this writing these costs ranged from \$0.60 to \$1.50/yd.^{2} for fabrics in the range 4.0 to 10.0 oz./yd.^{2}, with installation costs being an additional \$0.10 to \$0.50/yd.^{2} depending on the site conditions, quantity involved, and particular application.

It should also be recognized that fabric availability is sometimes very important. In aggressively marketed areas, many fabrics are available and the free-market system will sort things out. In more remote areas, however, where only one or two fabrics are available, design must necessarily reflect this situation. It is totally unrealistic to think that

TABLE 2.21 REQUIRED DEGREE OF SURVIVABILITY AS A FUNCTION OF SUBGRADE CONDITIONS AND CONSTRUCTION EQUIPMENT*

	Construction equipment and 6 to 12 in. of cover material: initial lift thickness		
Subgrade conditions	Low ground-pressure equipment ($\leq$4 lb./in.^{2})	Medium ground-pressure equipment ($\geq$4 lb./in.^{2}, $\leq$8 lb./in.^{2})	High ground-pressure equipment ($\geq$8 lb./in.^{2})
Subgrade has been cleared of all obstacles except grass, weeds, leaves, and fine wood debris. Surface is smooth and level such that any shallow depressions and humps do not exceed 6 in. in depth or height. All larger depressions are filled. Alternatively a smooth working table may be placed.	Low	Moderate	High
Subgrade has been cleared of obstacles larger than small to moderate-sized tree limbs and rocks. Tree trunks and stumps should be removed or covered with a partial working table. Depressions and humps should not exceed 18 in. in depth or height. Larger depressions should be filled.	Moderate	High	Very High
Minimal site preparation is required. Trees may be felled, delimbed, and left in place. Stumps should be cut to project not more than 6 in. ± above subgrade. Fabric may be draped directly over the tree trunks, stumps, large depressions and humps, holes, stream channels, and large boulders. Items should be removed only if placing the fabric and cover material over them will distort the finished road surface.	High	Very High	Not Recommended

*Recommendations are for 6 to 12 in. initial lift thickness. For other initial lift thicknesses:
12 to 18 in.: reduce survivability requirement one level;
18 to 24 in.: reduce survivability requirement two levels;
>24 in.: reduce survivability requirement three levels;
Survivability levels are in increasing order: low, moderate, high, and very high.
For special construction techniques such as prerutting, increase fabric survivability requirement one level.
Placement of excessive initial cover material thickness may cause bearing failure of soft subgrade.

Source: After Christopher and Holtz [125].

manufacturers will "tailor-make" a fabric to your design specification if it involves only a small quantity for a remote area.

In a similar vein, union situations have been known to affect costs, as has patent infringement in certain select areas.

2.11.4 Summary

At the heart of any well-designed facility is its proper and careful construction. In my personal investigations of geotextile-related failures, only six failures were design-related (two were clogging problems, two retention problems and two low-strength problems); all the others (approximately 12) were construction-related. Of the latter group, two were loss of strength due to excessive UV exposure, two were from lack of proper overlap on soft soils (sewing would have undoubtedly helped), and the remaining were caused by high installation stresses with respect to the fabric's mechanical properties. In the latter cases the "high" or "very high" survivability chart recommendations of Table 2.22 would have probably resulted in satisfactory performance. To be sure, construction is a vital part of design—it can never be overlooked.

TABLE 2.22 AASHTO-ABC-ARBTA JOINT COMMITTEE MINUMUN FABRIC PROPERTIES RECOMMENDED FOR FABRIC SURVIVABILITY[a] (approved 1989)

Required degree of fabric survivability	Grab strength[b] (lbs.)	Puncture strength[c] (lbs.)	Trap tear[d] (lbs.)
Medium	180/115	70/40	70/40
High	270/180	100/75	100/75

(a) All values represent minimum average roll values. First number for failure elongation less than 50%; second number for failure elongation greater than 50%

(b) ASTM D4632-85, either principal direction

(c) ASTM D3787-86

(d) ASTM D4533-85 either principal direction

2.12 REFERENCES

1. *Annual Book of Standards*, Parts 31 and 32, "Textiles: Yarns, Fabrics and General Test Methods," Philadelphia, PA: ASTM.
2. Kaswell, E. R., *Handbook of Industrial Textiles*, New York: West Point Pepperell, 1963.
3. Booth, J. E., *Principles of Textile Testing*, London: Newnes-Butterworths Publ., 1968.
4. Morton, W. E. and Heart, J. W., *Physical Properties of Textile Fibers*, New York: John Wiley & Sons, Inc., 1975.
5. Haliburton, T. A., Fowler, J. and Langan, J. P., "Design and Construction of a Fabric Reinforced Test Section at Pinto Pass, Mobile, Alabama," *Trans. Res. Record #79*, Washington, DC, 1980.
6. Myles, B. and Carswell, I., "Tensile Testing of Geotextiles," *Proc. 3rd Intl. Conf. Geotextiles*, Vienna, 1986, pp. 713-718.
7. McGown, A., Andrawes, K. Z. and Kabir, M. H., "Load-Extension Testing of Geotextiles